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# Getting Flat Surfaces in Turning

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**Abstract:** In this article we consider an issue of manufacture cost reduction of small-envelope pipes such as bodies of revolution by cutting time of their manufacture by means of part process by the whole toolheads installed at the equipment, with the processing of one of them with complex surfaces on the turning machines of turning lengthwise. It is possible to compensate drive/brake of cross-feed motion upon receipt of flat surfaces, in the case of turning machine of turning lengthwise of instrument in toolhead making the rotational motion of cutting tool with the aim of cutting end adaptation normally to working surface. The presented theoretical researches allow to make a conclusion about the possibility to process surfaces in turning. We offer an approach to the creation of automatic lathes using the modularity of assembly, in this case the new partial decision is placed between automatic lathes of past generation and modern turning centers as quickly retooled processing modules which have all necessary characteristics for process of small-envelope precision figurine-shaped workpieces.

**Key words:** Algorithm · Surface · Drive · Tool · Toolhead · Synchronization · Allowance · Chipping · Automatic lathe · Program control · Mechanism · Adaptive · Module · Mechatronic.

## INTRODUCTION

Workpieces receiving by turning by symmetrical bodies of rotation, asymmetry of such bodies may be available in flattened surfaces or in angular surface [1]. At the same time, some workpieces can be consisted of rotation bodies combination and parallelepipeds, hexagons and others.

Standard technological processes of workpieces receiving by turning include turning and milling [2]. Using automatic lathes of turning lengthwise in mass production include additionally cutter head. In such a way, receiving of the workpieces at the automatic lathe of turning lengthwise is concerned with the certain difficulties, because stiffness of manufacturing system is needed, receiving the flat surfaces needs additional cycle, that ultimately increases the time of receipt of the workpieces and in consequence its prime cost and technological equipment is rather complicated and requires the sophisticated control algorithms. Reduction of time of workpieces manufacture at the automatic lathe of turning lengthwise is achieved by simultaneous processing of workpiece with the whole saddles and if the part of them will be used for flat surfaces, than, in this case, reduction of time will happen, but for that, the control program for saddles should be developed, that make the working motion for the flat surfaces receiving [3].

**Main Part:** For control program development, it is necessary to understand the algorithm of cutting tool motion which the cutter is [4].

For development of algorithm of tool motion, we go into particulars the method of producing of flat longitudinal surfaces in turning. For this the authors use the scheme presented at the Figure 1(a); there is a cyclogram of tool motion at the Figure 1(b) [5]. This scheme of the method of producing of flat longitudinal surfaces offers the consistent obtain of flat surface 2 in the process of tool motion 3 in the body of workpiece 1 in the process of one rotation, at that, the workpiece is informed with two motion: rotational ù [omega] and longitudinal motion Spr and mechanism – Spop, according to diagram at the Picture 1, b.

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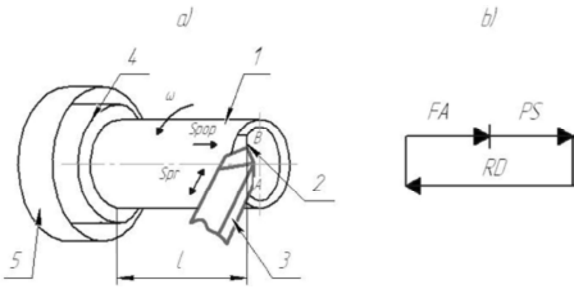


Fig. 1: a) The scheme of flat surface receiving; b) The cyclogram of tool motion.

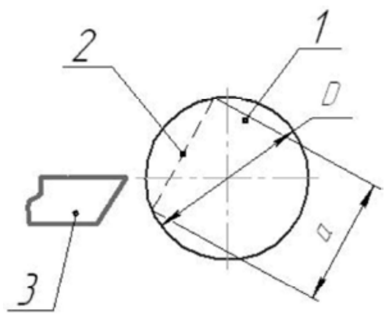


Fig. 2: The scheme of flattened surface receiving.

At that, the longitudinal motion should be synchronized with work piece rotation. In machining, the work piece 1 is anchored through stay bush 4 in collect closing mechanism 5 and point of cut (or cut surface) is placed at the distance 1.

In the performance of a task concerning the development of algorithm, it is necessary to define the speed of cutting tool according to diagram at the picture 1, b $V_{FA}$, $V_{PS}$, $V_{RD}$, to define the critical maximal force appearing in allowance removal, coupled with maximum allowable distance of work piece escape, or position of cut surface.

For traverse speed determination of cutting tool, we draw out a scheme of surface receiving, in our case – it is flattened surface.

We consider that flattered surface should be gradually taken off for several turns of detail, because the operation like a chipping should be made, so during several rotations the surface 2 is forming. When we know the length of flattered surface, than we can determine the number of rotations for which we can get flattered surface [1]:

$$B = \frac{Snp}{b} rotation, \quad (1)$$

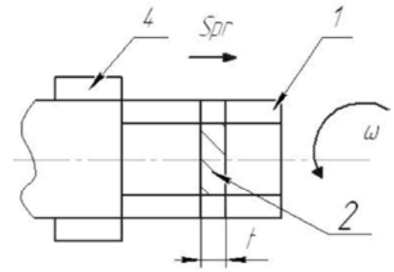


Fig. 3: Size determination of min material layer measuring on each rotation of work piece.

Similarly, we can determine the layer depth of material measuring on each rotation according to Figure 3.

As we can see from the picture, in motion of edge of flattered surface 2, the width of the thickness of the cut layer to its end is increasing and has the maximum (t→max) in tool escape in order to calculate its size, it is necessary to know which part of rotation is flattered surface, that is easily determined from the geometric schemes. According to them: $t\max = Snp \cdot \frac{2\arcsin(l/D)}{360}, mm$ , at that we should use the value of longitudinal motion.

Determination of motion speed is made in accordance to scheme 1, b, at that the max size of cut tool motion (1i) is:

$$li_{\max} = \frac{D}{2} - \arccos(l/D) \cdot \frac{D}{2}$$

*or*

$$li_{\max} = \frac{D - \arccos(l/D) \cdot D}{2}, mm$$

When we know the rate of rotation r/min and diameter of work piece D, then we can define $V_{PS}$.

Traverse speed of tool during allowance removal:

$$V_{PS} = 2 \cdot \frac{\Delta \cdot t_{\Delta}}{60} mm/s,$$

where Δ [delta] – total allowance on flattered surface, mm; $t_{\Delta}$- time of cutting for one rotation, s/r.

Please note that $V_{RD}$ and $V_{FA}$ should be synchronized too with $V_{zag} = \frac{\pi Dn}{1000}$, simple calculations show that for example $V_{FA}$ in movingat the distance 1 should be no more than $V_{FA} = \frac{l}{t_{AB}/2}$, where $t_{AB}$, since the time of part moving from the end to the initial to the final point of flattened surface, during receipt of flattened surface located on the axis of part. This time will be equal to: $tAB = \frac{1000}{\pi n} \cdot 120.$ Define the model procedure of this time.

Suppose, that work piece with diameter D=5 mm is processed in machine, process is made at the run-away speed of spindle – 30000 r/min, than we receive $t_{AB} = \frac{1000}{3,14 \cdot 30000} \cdot 120 = 8 \cdot 10^{-5}$ sec. Lets check the speed of cutting in the turning $V_r = \frac{\pi Dn}{1000} \cdot 120 = 471 m/\min,$ it overturns the recommended value and tool traverse speed has considerable extent, so the real speed of cutting should be mentioned recommended by manufacturers of tool [6]. In such a way, the time of work piece process is 0,002 sec at the mentioned above speed and the speed of rotation of 1° (degree) is 5,5*10-6 correspondingly, maximum value of end-effector movement is counted on as follows: $li_{\max} = \Delta + l,$ where Δ [delta] – max depth of flattened surface, for our example, with surface placement at the axis of work piece $li_{\max} = 5/2 + 5 = 7{,}5 mm$, upon condition that for the time of operating time, the work piece is moved by 90 ° (degrees), we account the time of working travel in one direction $li_1 = 90° \cdot 5{,}5 \cdot 10^{-6} = 0{,}0005$sec, that is acceptable, because drive must provide the travel with frequency 2000 Hz, that is possible for modern mechanical system by using of ball screw assembly and intermittent drive.

You should also make a possibility to ensure the accuracy of the location of the produced surface, because tool supply is not synchronized with the rotation of the work piece or not providing of machine of dampening plane by support, as the beginning and the end of the shift. As the sensors of frequency of rotation of a spindle and simultaneously the angle of rotation are used incremental encoders with discreteness of 2500 imp/r (impulse/ rotation) but more often used with discretion of 3600 imp/r, at the condition of the accuracy of positioning of the working body with an error of ±1%. Perform the calculation to determine the offset of received plane, for which we elaborate the design scheme, for the case when the plane is located on the axis of the work piece, the scheme is presented at the Figure 4.

Besides, there are different combinations of the start αtн [alpha] and the end angle αtk. [alpha]. The most dangerous combination is αtн(-)- αtk(+), or αtн(+)- αtk(-), because at this case the offset to the double angle is appeared. The absolute value of the offset in this

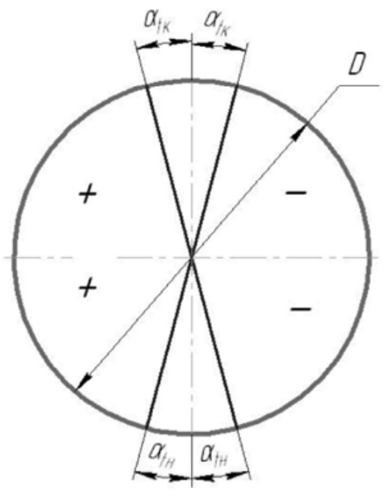


Fig. 4: Offset of plane and positioning error of the tool.

case can be determined from the condition: $\Delta t_H = 2 \cdot \sin\alpha_{tn} \frac{D}{2} = \sin\alpha_{tH} \cdot D$ in the case of offset of displacement in a positive and negative direction of the beginning and the end of the surface profile: $\Delta t = \sin\alpha_{tH} \cdot D + \sin\alpha_{tk} \cdot D = D \cdot (\sin\alpha_{tH} + \sin\alpha_{tk})$.

Check this condition for our example (D=5) $\Delta t = 5 \cdot (\sin 1° + \sin 1°) = 0{,}087 mm$, that this diameter is clearly unacceptable, therefore it is necessary to start from an initial margin of error of deviation of a surface, that is surface with the limit of 0,01 mm; determine the angle: $\alpha = \arcsin(\frac{0{,}01}{5})/2 \approx 0{,}05°,$ that impossible to provide with the modern controls equipment. If, however, proceed from the condition, obviously, it should formulate a particular hardware device: $\arcsin(\frac{\Delta}{D}) < \Delta°C,$ where $\Delta°C$ - permissible positioning accuracy of the working body of the equipment provided by synchronization movements. Therefore, before you launch a product in the processing according to the rules of designing of technological processes, you should perform a check of the possibility of obtaining surfaces.

An important feature of the receipt of flat surface when machining is to ensure the simultaneous movement of the tool and the work piece and the desired angle of cutting wedge should be always provided to perform rent of allowance; the scheme of such process is at the Figure 5.

The rent of allowance Δ [delta] in surface receiving 2 at the work piece 1 is made by tool 3, which must be always placed in quadrature φ=90° to flattened surface,

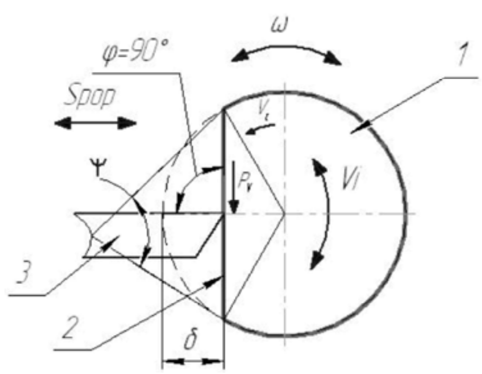


Fig. 5: The scheme of rent of allowance.

only in that case we can project the process of cutting: it is not happening tool wear, cutting efforts are minimal, it does not occur the deflection or breakage of the tool.

In that case, if the cutting edge is always placed normally to receiving (working) surface, then calculation of cutting force can be made similar to calculation in facing operation, besides the depth of cutting should be maximum accordant with the scheme at the Figure 3. Known formula of Zvorykin K.A. [8] is used in calculation of force acting on a cutter and work piece. It allows you to do the calculation taking into account the shear section, but for this the additional tests are necessary. Therefore, the authors decided to use a formula to calculate the cutting force when turning, adapting it to the scheme shown in the Figure 5.

$$Pz = 10 \cdot Cp \cdot \delta^{Xp} \cdot \left(\frac{t}{2}\right)^{yp} \cdot V \cdot Kp, H$$

where Δ [delta] – is the maximum displacement of receiving surface, mm; t – according to scheme at the Figure 3, the maximum width of cutting layer, mm, because at the maximum value of Δ [delta], the value of cutting layer is half of the maximum value, then a denominator – 2 is appeared; Xp – empirical exponent in turning at the depth of cutting; Yp - empirical exponent in turning at feeding, $n_p$ – exponent used for speed; K – corrective factor taking into account the actual conditions of cutting.

You should know that force of cutting indices not only the holder deflection of cutting tool and the work piece too [9]. Work piece deflection depends not only for cutting force and for maximum flying of work piece and according to scheme at the picture 1, this force is applied to the stay bush 4 and that can cause the early wear of the latter. Therefore, the cutting force becomes the limiting factor in the appointment of modes of cutting and is also considered in determining the possibility of the details of the specific equipment [10].

Vector of cutting speed V is a sum of two vectors – vector of work piece speed determined by the frequency of rotation and the speed vector of movement of the tool during its turn Vi. Such vectors addition allows to decrease the traverse speed of tool during realization of cutting scheme presented at the Figure 5. Such vectors addition is possible only in condition of possibility of cutting tool rotation at the corner β [beta] (Figure 5), formed by the initial and final point of the surface and the center of the work piece that hard to implement, because in the case of flattened surface receive on the axis of the work piece this angle changes from -45° to +45°, that's why it is necessary to account as maximum possible speed of supply, as speed of cutting tool rotation. In case of equality of angles ø [psi] and β [beta], speed of rotation of the cutting tool is equal to the speed of cut, otherwise it needs to recalculate the mismatch of nodes. But the important advantage is the absence of cross feed because the need for a cross dragging of the tool is dropped. If the corner of flat surface is more than corner of tool rotation, than the cross-feed motion of cutting tool is necessary; but the moving of corner is less, so the traverse speed is less [11].

Thus, you receive the following parameter, possibly acting as a limitation – it is the maximum angle of rotation of the cutting tool.

When developing a management program of management by tool movement of support used to produce flat surfaces, it is need to prepare the specification of the output and input actions [12; 13].

**Make the Specification of the Output Parameters:**

- Rotation speed of tool;
- Cross travel rate;

**Make the Specification of the Input Parameters:**

- Work piece diameter;
- Surface placement, or its distance from the edge of work piece;
- Maximum permissible or maximum allowable cutting force;
- Maximum rotation angle of tool;
- Maximum rotation speed of tool and maximum rate of feeding;
- Accuracy of receiving surface.

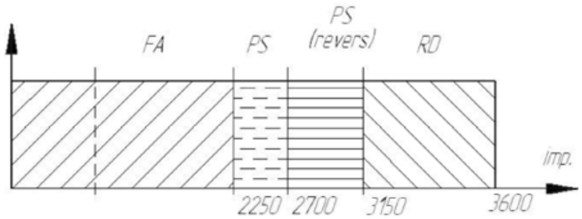

Fig. 6: The scheme of control by feed at the base of impulsive calculation.

If the first five parameters are technological, the last parameter is a designer×s condition.

Describe the algorithm of control by equipment, realizing a sequence diagram of the tool, shown in the Figure 1, b [14]. From the previous discussion, it is clear, that the size of min allowance depends on the part placement, cutting force and offset of the tool; they are made in a strictly predetermined angle of part rotation and this makes necessary to use the spindle velocity sensor or, in our case, the spindle angle sensor. In the case of sensor absence in the equipment, it should be installed and as it was mentioned above, the incremental encoder is used as an angle sensor. Feature of the sensor is the following: it during the rotation generates a sequence of pulses, the number of pulse and allows to calculate the current rotation of the work piece; for example, at the angle of surface in 90°, using the angle of work piece placement of rectangular coordinate system, according to scheme at the Picture 5, cutting will be made at pulses input of 2250 (encoder has 3600 pulse/rot) and the offset with input 3150 pulses. Similar to this, we can make the angle scaling of pulses with another quantity of pulses per rotation. Therefore, the whole parameters of control by migration of tool are passed to impulsive calculation that makes the control easier. For example, the control scheme of cross feed is at the Figure 6 (for our example).

From zero to 2250 pulses occurs quick supply of the tool, with 2250 pulse begins cutting, with 2700 pulse turns on the reverse is the formation of the second half of the surface, with 3150 pulse is rapid removal tool. In the case of «ideal» drives this sequence diagram actuator cross feed are feasible, but "real" drive require acceleration-deceleration, it does not allow to implement constantly on the 2700 pulse, therefore, to a certain moment (braking) you must enable the turn tool and turn it off with the end of the crackdown, but in the reverse direction.

## CONCLUSION

Thus, if there in a support [1; 15] equipment (lathe machine of longitudinal turning) of mechanism performs the rotation of the cutting tool with the purpose of adaptation of the cutting edge along the normal to the processed surface, it is possible to compensate acceleration-deceleration cross feed, upon receipt of the flat surfaces. Construction of a sliding headstock bar machine based on adaptive modules will allow to increase productivity of the equipment and hence reduce the cost of such equipment products.

**Summary:** Theoretically, we proved the possibility of obtaining the flat surfaces at turning, provided that the requirements for the maximum permissible force of cutting, calling deflection of the cutting tool and offset procurement wear of stay bush. Lay the foundation of a new direction in the high-performance machining of small parts, when creating the modular design of sliding headstock bar machine based on adaptive mechatronic modules.

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